

CLAIMS

1. A method for yielding transient solutions for the film-blowing process by using a film-blowing process model characterized that the following governing equations in consideration of the viscoelasticity and cooling characteristics of the film are first solved; and then, through coordinate transformation, the free-end-point problem is changed into a fixed-end-point problem; and finally, by introducing Newton's method and OCFE (Orthogonal Collocation on Finite Elements), the transient solution for the film blowing process is obtained:

Equations:

$$\frac{\partial}{\partial t} \left(r w \sqrt{1 + \left(\frac{\partial r}{\partial z} \right)^2} \right) + \frac{\partial}{\partial z} (r w v) = 0 \quad \dots (1)$$

Here,

$$t = \frac{\bar{t} v_0}{r_0}, z = \frac{\bar{z}}{r_0}, r = \frac{\bar{r}}{r_0}, v = \frac{\bar{v}}{v_0}, w = \frac{\bar{w}}{w_0}$$

Axial direction:

$$\frac{2rw[(r_{11} - \tau_{22})] + 2r\sigma_{surf}}{\sqrt{1 + (\partial r / \partial z)^2}} + B(r_p^2 - r^2) - 2C_{gr} \int_0^{z_L} r w \sqrt{1 + (\partial r / \partial z)^2} dz - 2 \int_0^{z_L} r T_{drag} dz = T_z \quad \dots (2)$$

Here,

$$T_z = \frac{\overline{T_z}}{2\pi\eta_0 w_0 v_0}, \quad B = \frac{\overline{\tau_0^2 \Delta P}}{2\eta_0 w_0 v_0}, \quad \Delta P = \frac{A}{\int_0^{z_L} \pi r^2 dz} - P_\infty, \quad \tau_{ij} = \frac{\overline{\tau_{ij} \tau_0}}{2\eta_0 v_0}$$

$$C_{gr} = \frac{\overline{\rho g r_0^2}}{2\eta_0 v_0}, \quad T_{drag} = \frac{\overline{T_{drag} \tau_0^2}}{2\eta_0 v_0 w_0}, \quad \sigma_{surf} = \frac{\overline{\sigma_{surf} \tau_0}}{2\eta_0 v_0 w_0}$$

5 Circumferential direction:

$$B = \left(\frac{[-w(\tau_{11} - \tau_{22}) + 2\sigma_{surf}](\partial^2 r / \partial z^2)}{[1 + (\partial r / \partial z)^2]^{3/2}} + \frac{w(\tau_{33} - \tau_{22}) + 2\sigma_{surf}}{r \sqrt{1 + (\partial r / \partial z)^2}} - C_{gr} \frac{\partial r / \partial z}{\sqrt{1 + (\partial r / \partial z)^2}} \right)$$

... (3)

10 Constitutive Equation:

$$K\tau + De \left[\frac{\partial \tau}{\partial t} + v \cdot \nabla \tau - L \cdot \tau - \tau \cdot L^T \right] = 2 \frac{De}{De_0} D$$

... (4)

Here,

$$K = \exp[\epsilon De \text{tr} \tau], \quad L = \nabla v - \xi D, \quad 2D = (\nabla v + \nabla v^T), \quad De_0 = \frac{\lambda v_0}{\tau_0},$$

$$De = De_0 \exp \left[k \left(\frac{1}{\theta} - 1 \right) \right]$$

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Energy equation:

$$\frac{\partial \theta}{\partial t} + \frac{1}{\sqrt{1 + (\partial r / \partial z)^2}} \frac{\partial \theta}{\partial z} + \frac{U}{w} (\theta - \theta_c) + \frac{E}{w} (\theta^4 - \theta_\infty^4) = 0$$

... (5)

Here,

$$\theta = \frac{\bar{\theta}}{\theta_0}, \theta_c = \frac{\bar{\theta}_c}{\theta_0}, \theta_\infty = \frac{\bar{\theta}_\infty}{\theta_0}, U = \frac{\bar{U}r_0}{\rho C_p w_0 v_0}, \bar{U} = \alpha \left(\frac{h_{air}}{z} \right) \left(\frac{\rho_{air} \bar{v}_c z}{\eta_{air}} \right)^\beta, E = \frac{\epsilon_m \sigma_{SD} \bar{\theta}_0^4 r_0}{\rho C_p w_0 v_0 \theta_0}$$

Boundary conditions:

$$5 \quad v = w = r = \theta = 1, \tau = \tau_0 \quad \text{at } z=0 \quad \dots (6a)$$

$$\frac{\partial r}{\partial t} + \frac{\partial r}{\partial z} \frac{v}{\sqrt{1+(\partial r/\partial z)^2}} = 0, \frac{v}{\sqrt{1+(\partial r/\partial z)^2}} = D_R, \theta = \theta_F$$

at $z=z_F \quad \dots (6b)$

wherein, r denotes the dimensionless bubble radius,
 10 w the dimensionless film thickness, v the dimensionless
 fluid velocity, t the dimensionless time, z the
 dimensionless distance coordinate, ΔP the air pressure
 difference between inside and outside the bubble, B the
 dimensionless pressure drop, A the air amount inside the
 15 bubble, P_a the atmospheric pressure, T_z the dimensionless
 axial tension, C_{gr} the gravity coefficient, T_{drag} the
 aerodynamic drag, σ_{surf} the surface tension, θ the
 dimensionless film temperature, τ the dimensionless stress
 tensor, D the dimensionless strain rate tensor, ϵ and ξ the
 20 PTT model parameters, De the Deborah number, θ_0 the zero-
 shear viscosity, K the dimensionless activation energy, U
 the dimensionless heat transfer coefficient, E the

dimensionless radiation coefficient, k_{air} the thermal conductivity of cooling air, ρ_{air} the density of cooling air, η_{air} the viscosity of cooling air, v_c dimensionless cooling air velocity, α and β parameters of heat transfer coefficient relation, θ_c the dimensionless cooling-air temperature, θ_∞ the dimensionless ambient temperature, ϵ_m the emissivity, σ_{SB} the Stefan-Boltzmann constant, ρ the density, C_p the heat capacity, D_R the drawdown ratio;

the assumption was made that no deformation occurred in the film past the freezeline at the boundary conditions; overbars denote the dimensional variables; subscripts 0, F and L denote the die exit, the freezeline conditions and the nip roll conditions, respectively; and subscripts 1, 2 and 3 denote the flow direction, normal direction, and circumferential direction, respectively.

2. The method for yielding transient solutions for the film-blowing process by using a film-blowing process model according to claim 1, wherein the non-isothermal process model is a numerical scheme for yielding transient solutions for the film-blowing process, which has three multiplicities.

3. In a nonlinear stabilization analysis method of a process, the improvement comprising that it is an analysis method that utilizes the temporal pictures obtained from the numerical scheme in Claim 1.

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4. A method for the optimization of the process which is obtained by use of a sensitivity analysis of the relative effects affecting the stability of each process variable through a transient solution, which was calculated and yielded in the course of deduction of the transient solutions for the film-blowing process in Claim 1.

5. An apparatus necessary for the optimization and stabilization of the process, which utilizes the numerical scheme stated in Claim 1.